Stage 30 (Figure 15)

Hatching and loss of yolk sac occur. The larva becomes free-swimming, darting about near the surface of the aquarium or fingerbowl with the mantle pointed upward at an angle.

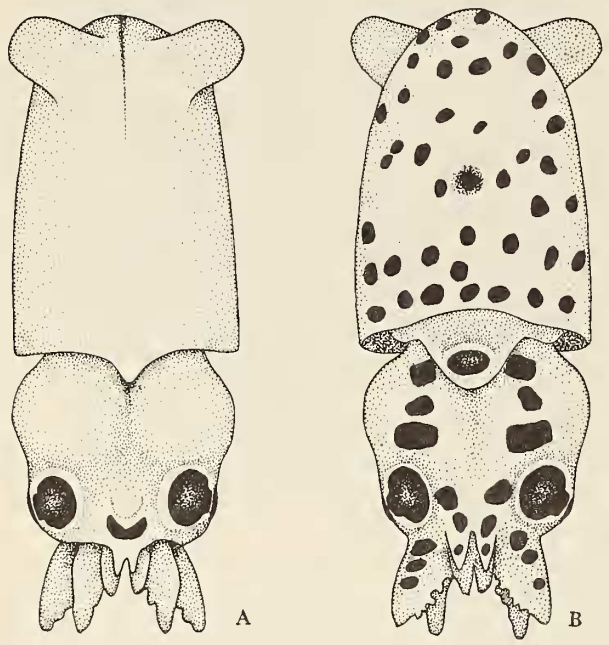

Figure 15

Lolliguncula brevis

Gross morphology of Stage 30 embryo. A, dorsal; B, ventral
Length from tip of tail to tip of arms: 3.1 mm

DISCUSSION

The criteria of normal embryonic stages established by Arnold (1965) for *Loligo pealii* were followed in studying post-cleavage morphology in *Lolliguncula brevis* since they are based on morphological events rather than timing of development. The pattern of development in *Lolliguncula brevis* is similar enough to that recorded for *Loligo pealii* that identical stage designations may be used for both species. However, care must be exercised in organizing such a series for any species under consideration. Species differences in the relative timing of minor developmental events (*e.g.*, appearance of chromatophores) will necessitate the use of a combination of selected characters carefully chosen for their comparative value (mainly gross morphology). The value of such a staging system lies in that it tends to amplify differences between closely-related species, thus providing an excellent basis for comparison.

In any study based on Arnold's stages, problems may arise when preserved material is used, since he included several characters visible only in living individuals.

It is quite evident that once similar stages are established for other loliginid species, the embryonic differences among the species themselves, such as time of appearance and distribution of chromatophores, might be used in larval identification.

The present study provides some basis for comparison within the Loliginidae, but offers little support for comparative discussion or evolutionary speculation with other families of decapod orders, since there is a decided lack of detailed embryological studies on most decapod cephalopods (excluding those on *Sepia officinalis*).

Gross external morphological development in loliginid squids appears to be extremely homogeneous. In all 4 species studied to date, few specific differences appear. The only notable difference is the chronology of appearance and placement of mantle chromatophores. Chromatophores on both dorsal and ventral surfaces of the mantle appear about Stage 25 in *Loligo opalescens* (Fields, 1965) and on the ventral surface at Stage 26 and dorsal surface at Stage 27 in *Loligo pealii* (Arnold, 1965) and *Loligo bleekeri* (Hamabe, 1960). Pigmentation begins in the ventral chromatophores at Stage 26 in *Lolliguncula brevis,* while dorsal chromatophore pigmentation does not appear until after Stage 30. No other differences in gross morphological development during organogenesis are apparent between *Lolliguncula brevis* and other loliginid species.

Portmann & Bidder (1928) have divided the time of yolk absorption in *Loligo* sp. into four different periods. The first period extends from cleavage to the establishment of embryonic circulation (Stages 1 through 20); the second from first contractions of the external yolk sac to breakdown of the circulatory pattern by the contraction of the circumoral musculature (Stages 20 through 26); the third period ends with hatching and loss of the external yolk sac (Stages 26 through 30), the fourth period extends from the loss of the external yolk sac to complete absorption of the yolk in the free-swimming individual. Portmann & Bidder (*op. cit.*) state that the third period in-

cludes the fastest growth rate for the internal yolk sac, which reaches its maximum size during this period. The increases in size in *Lolliguncula brevis* seen between stages 25 and 26 (see Figure Explanations for measurements) may thus be explained on the basis of increase in growth rate of the internal yolk sac in the latter stage, causing an overall increase in the length of the embryo itself (excluding the external yolk sac).

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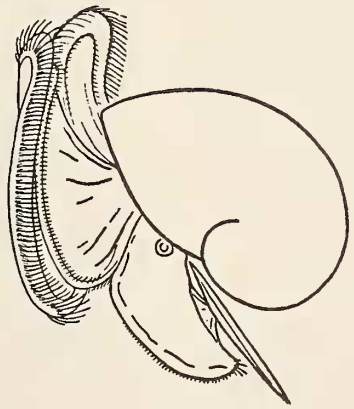

Carnivorous *Calliostoma*

(Prosobranchia : Trochidae)

from the Northeastern Pacific

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(1 Plate)

INTRODUCTION

The prosobranch archaeogastropod Mollusca have traditionally been described as herbivores and deposit scrapers (Morton, 1968). However, well known examples of carnivorous feeding behavior in the rhipidoglossate archaeogastropoda include fissurellid limpets of the genera *Diodora* and *Emarginula,* which feed on sponges (Graham, 1939), and the neritid *Theodoxus fluviatilis* (Linnaeus, 1758) which also includes sponges in its diet (Ankel, 1936). Another fissurellid limpet, *Megatebennus bimaculatus* (Dall, 1871) has been shown to eat colonial ascidians (Ghiselin, personal communication).

The family Trochidae, in particular, has been thought to be composed exclusively of herbivores (Abbott, 1968). It is not surprising, therefore, that Clench & Turner (1960) stated that all members of the trochid genus *Calliostoma* probably feed on algae, diatoms and plant detritus.

This paper reports on the diets of three sympatric species of Eastern Pacific *Calliostoma: C. annulatum* [Lightfoot, 1786], *C. variegatum* (Carpenter, 1864) and *C. ligatum* (Gould, 1846), the first two of which have been found to feed extensively on hydroids and possibly on a variety of other animal prey.

Laboratory observations of predation by species of *Calliostoma* on anemones (Frances, 1973), limpets (Coan, personal communication) and on scleractinian coral (Miller, 1972) have been reported. Lowry, McElroy & Pearse (1974) have suggested that species of *Calliostoma* may feed on sessile animals in the California kelp forest they studied. However, the gut analyses and field observations included in the present study constitute the first sound evidence for carnivorous feeding in genus *Calliostoma.*

MATERIALS and METHODS

Specimens of *Calliostoma annulatum, C. variegatum* and *C. ligatum* were collected and studied in the vicinity of San Juan Island, Washington, June to August, 1974. The study included approximately 10 hours of field observations using SCUBA equipment, gut analyses of 85 *C. ligatum,* 56 *C. annulatum* and 8 *C. variegatum,* and laboratory feeding experiments.

The SCUBA observations were conducted off Eagle Point, San Juan Island, and extended to a depth of 30 m. A total of 26 *Calliostoma annulatum* were collected for gut analyses during these dives. The balance of the specimens used for gut analyses were collected intertidally or dredged offshore. Dredge hauls included 52 *C. ligatum* and 23 *C. annulatum* from 80 m, 4 *C. annulatum* and 8 *C. variegatum* from 106 m, and 3 *C. annulatum* from 190 m. All dredge hauls were made on shell, cobble and rock bottoms using a rock dredge. In addition, 23 *C. ligatum* were collected intertidally on San Juan Island.

Gut analyses consisted of removing the contents of stomach and intestine from specimens fixed in formalin and examining this material under dissecting and compound microscopes. Rough estimates were made of the relative proportions of detritus, diatoms and animal material.

Laboratory feeding experiments were conducted on 40 specimens of *Calliostoma annulatum* collected off Eagle Point. Twenty of these animals were starved for 2 weeks while the remaining were kept well supplied with several types of algae, thecate and athecate hydroids, ectoprocts, organic detritus and a variety of anemones and nudibranchs. At the end of 2 weeks, both groups of *C. annulatum* were offered a range of food types. The function of the starved controls was to determine if my own labora-